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REPORT NO. 2

PROCESS MODELING OF BIOLOGICAL WASTE TREATMENT

ANNUAL PROGRESS REPORT

D. M. Himmelblau
E. F. Gloyna

OCTOBER 10, 1970

Supported by

U.S. ARMY MEDICAL RESEARCH AND DEVELOPMENT COMMAND
Washington, D.C. 20315

Contract No. DADA 17-69-C-9073

The University of Texas
Austin, Texas 78712

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SUMMARY

This report describes the work undertaken to represent and identify mathematical models of biological waste treatment as applied to a laboratory sized aeration basin. Pulse inputs of radioactive sodium-24 have been used to obtain residence time distribution curves (impulse response curves) for the basin. Various configurations of aerators indicated that even at high air flow rates complete mixing may not take place. Individual tanks and tanks in series were studied to evaluate some of the limiting factors that exist with respect to the use of population balance models in representing aeration basins.

FOREWORD

This investigation was authorized under contract DADA-17-69-C-9073 dated February 1, 1969, and is associated with the work of the Center for Research in Water Resources of The University of Texas.

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OBJECTIVES AND SCOPE OF INVESTIGATION

Improvement in the prediction of waste purification rates requires better mathematical models of such processes as well as better data. The purpose of this investigation has been to study the modeling and identification of aerobic waste treatment methods, and to apply population balance techniques of process modeling to laboratory scale equipment in order to ascertain their representativeness.

EXPERIMENTAL RESULTS

1. Single Tank

The first four experiments were carried out in a small aeration tank to simulate an activated sludge process. The first three runs were made without the biomass present, while the fourth experiment was carried out with the biomass present to determine the effect the biomass had on the degree of mixing. Figure 1, a typical result, shows the corrected gamma ray counts per minute in the tank effluent stream as a function of time. (The gamma ray counts are directly proportional to the respective tracer concentrations, hence these figures represent concentration-time plots.) Table 1 summarizes the residence times and equivalent number of tanks for these four experiments, and provides evidence that the performance of the aeration tank could, as expected, be reasonably well determined using the tanks in series model based on the assumption that the contents of the tank are at all times completely mixed. The value for the equivalent number of tanks was calculated from the variance.

In the first four experiments the equivalent number of well mixed tanks calculated from the variance showed that the small aeration tank was well mixed (except for the second run). In Run 2 the high value for the equivalent number of tanks can be attributed to the fact that the experiment was terminated after only five volumetric residence times. The first experiment was truncated at approximately four times the mean residence time of 2.035 hours, resulting in an apparent mean residence time of 1.90 hours, an error of about five percent. When simulation was used to extend the experiment to nine residence times by assuming a linear drop in concentration, the average residence time was found to be 2.036 hours. The equivalent number of well mixed tanks corresponding to the cut off of four residence times was 1.31, whereas for nine residence times the value was 1.032, an error of 21%. Thus, the estimation of the equivalent number of well mixed tanks from the variance is more sensitive to the length of the data record than is the determination of the mean residence time, an observation made by others. Thus, in order to use the variance as an accurate

TABLE 1

EXPERIMENTAL RESULTS

RUN NO.	TANK NO.	EQUIVALENT NO. OF TANKS	MEAN RESIDENCE TIME (hr)	ACTUAL RESIDENCE TIME (hr)	EXP'L ERROR
1	1	1.032	2.036	2.035	0.050
2	1	1.320	0.617	0.600	0.014
3	1	1.009	0.646	0.641	0.011
4	1	0.953	2.226	2.145	0.040
5	1	1.425	15.47	12.500	0.300
6	1	2.107	17.55		
7	1	1.283	5.47	4.152	0.100
	1+2	1.770	8.20	8.136	0.197
	1+2+3	1.970	12.57	12.147	0.295
8	1	0.976	7.44	4.054	0.098
	1+2	1.205	8.39	8.051	0.196
	1+2+3	2.124	12.71	11.865	0.290
9	1	1.116	8.72		
	1+2	1.241	10.03		
	1+2+3	1.711	12.67		
10	1	0.762	4.65		
	1+2	1.659	8.42		
	1+2+3	2.595	12.14		
11	1	0.968	4.51		
	1+2	1.957	8.57		
	1+2+3	3.033	12.65		
12	1	0.843	5.26		
	1+2	1.685	9.31		
	1+2+3	2.532	12.14		

measure of the equivalent number of tanks in a well mixed system, the experiment must be carried out for several times the volumetric residence time.

Figure 2 plots dimensionless concentration versus dimensionless time ($C(\theta)$ versus θ) for the first four experiments, and indicates that the runs approximate the curve for one well mixed tank at all levels of air and liquid rates studied. Since experiment 4 (containing the biomass) also falls on the curve, it was concluded that the presence of a biological culture did not affect the degree of mixing.

2. Experiments Simulating an Elongated Aeration Tank

A large aeration tank was utilized to carry out two experiments simulating one elongated aeration tank with a length to width to depth ratio of 6:2:1. Figure 3 shows the output curves for a typical run. Table 1 summarizes the results of the calculations for the large aeration tank for runs 5 and 6. The two runs were replicates carried out at the same volumetric residence time without any aeration to determine the degree of mixing that existed in the system when no air was used. It was noted that there was a significant deviation in the equivalent number of tanks and in the mean residence times between the two runs. It was also noted that the peak for run 5 occurred at the second hour while the peak for the next experiment did not occur until the eighth hour. One possible reason for the differences in the number of tanks and the mean residence times for these two runs is that the tracer for experiment 5 was injected with a syringe just below the water level at the liquid inlet, while the tracer for run 6 was poured near the liquid inlet from a beaker. Since the latter method of pouring from a beaker would not disrupt the mixing patterns in the system as much as a pulse injection from a syringe, the pouring method was used for the remaining runs.

Figure 3 indicates that the experimental data did not fit the theoretical curve for the well mixed tanks in series model. Since the data does not approximate the curve, it was concluded that the elongated tank did not approach a well mixed system when there was no agitation in the aeration tank.

3. Experiments Simulating Tanks in Series

Six experiments were carried out in the large aeration tank with configurations arranged so as to simulate one, two and three tanks in series. Table 1 summarizes the results obtained. Experiment 11 was carried out in the presence of a biological culture to reaffirm the conclusion reached using

the small aeration tank that the biomass does not affect the degree of mixing in the basin.

Figures 4 and 5 illustrate typical experimental data, that for Run 8. Figure 4 shows that the theoretical curve for 0.976 tanks fit the experimental data quite well. Figure 5 reveals that the theoretical curves for 1.205 and 2.124 tanks in series fit the experimental data for the second and third tank except at the peak of the concentration curves. It was concluded that when the system was well mixed, the calculation of the equivalent number of well mixed tanks could be computed reasonably well from the variance.

Figure 6 shows a dimensionless plot of concentration as a function of time for the second tank in the series for experiments 9, 10, and 12. The figure reveals that the second tank for Run 9 more closely approached one well mixed tank, while the data after the second tank for runs 10 and 12 approximate two well mixed tanks in series.

4. Calculations from the Peak of the $C(\theta)$ Curve

Murphy and Timpany and others have suggested an alternative method for aeration tank design and analysis, namely using the peak of the $C(\theta)$ curve to estimate the dispersion coefficient and the number of tanks in series. The values obtained utilizing the peak of the $C(\theta)$ curve did not agree at all with the correct mean residence times or the dispersion coefficients computed from the tanks in series model. It was concluded that the use of the peak of the $C(\theta)$ curve to calculate the dispersion coefficient, mean residence time, and equivalent number of well mixed tanks was not satisfactory.

5. Conclusions

During the course of this investigation the following conclusions were reached:

1. Since the presence of a biological culture does not affect the degree of mixing in the system, experiments may be undertaken in existing aerobic waste treatment installations.
2. Na24 may be used in an aerobic waste treatment system as a tracer to estimate the empirical parameters in the model employed because Na24 does not influence the physical parameters of the fluid, does not undergo a chemical reaction, and is detectable in low concentrations.
3. If the system is well mixed, the experimental runs are reproducible.

4. Calculation of the mean residence time, dispersion coefficient, and equivalent number of tanks cannot be made from the peak of the $C(\theta)$ curve.

5. If the experiment is carried out to at least six times the volumetric residence time, the variance may be used as an accurate approximation of the equivalent number of well mixed tanks.

6. Plans for Future Work

Now that the mixing characteristics of the laboratory aeration basin have been determined, the next step is to determind the kinetics of well mixed processes with the biomass present. Depending upon the characteristics of the kinetic models, it should be possible to develop analytical and/or numerical methods to make predictions for degree of conversion of waste influent.

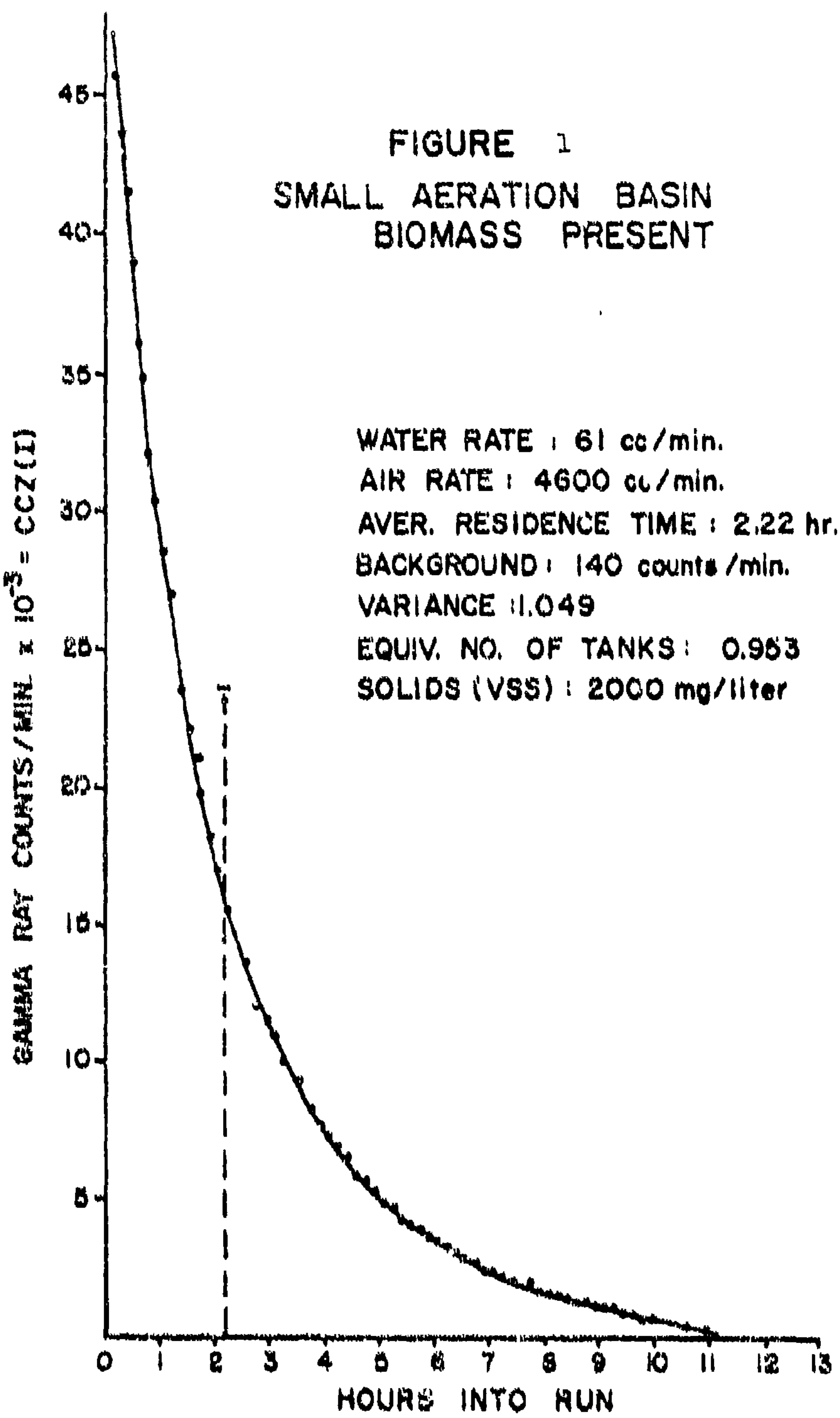


FIGURE 1
SMALL AERATION BASIN
BIOMASS PRESENT
WATER RATE : 61 cc/min.
AIR RATE : 4600 cc/min.
AVER. RESIDENCE TIME : 2.22 hr.
BACKGROUND : 140 counts/min.
VARIANCE :1.049
EQUIV. NO. OF TANKS : 0.953
SOLIDS (VSS) : 2000 mg/liter
GAMMA RAY COUNTS/MIN. x 10^-3 = CCZ(I)
45
40
35
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
HOURS INTO RUN

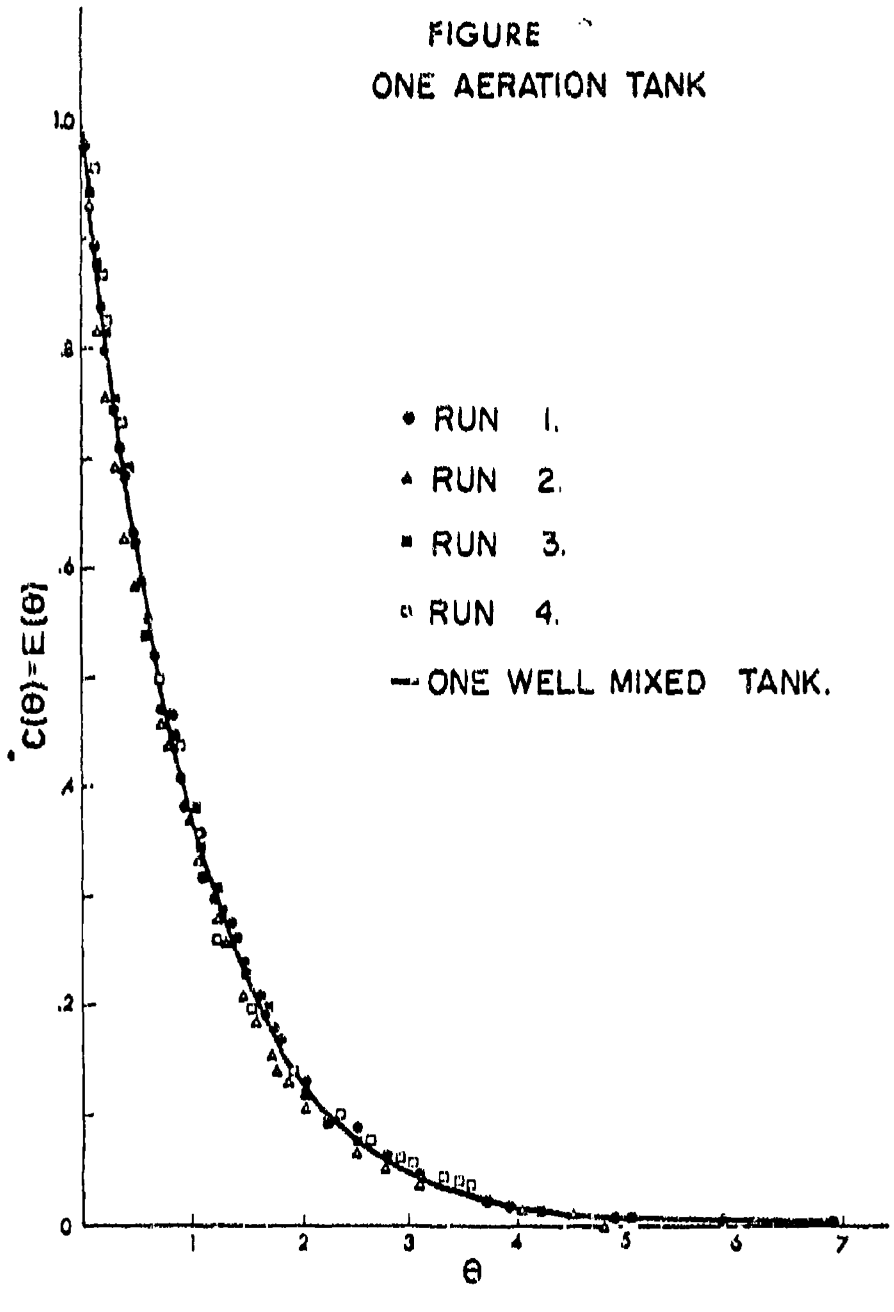
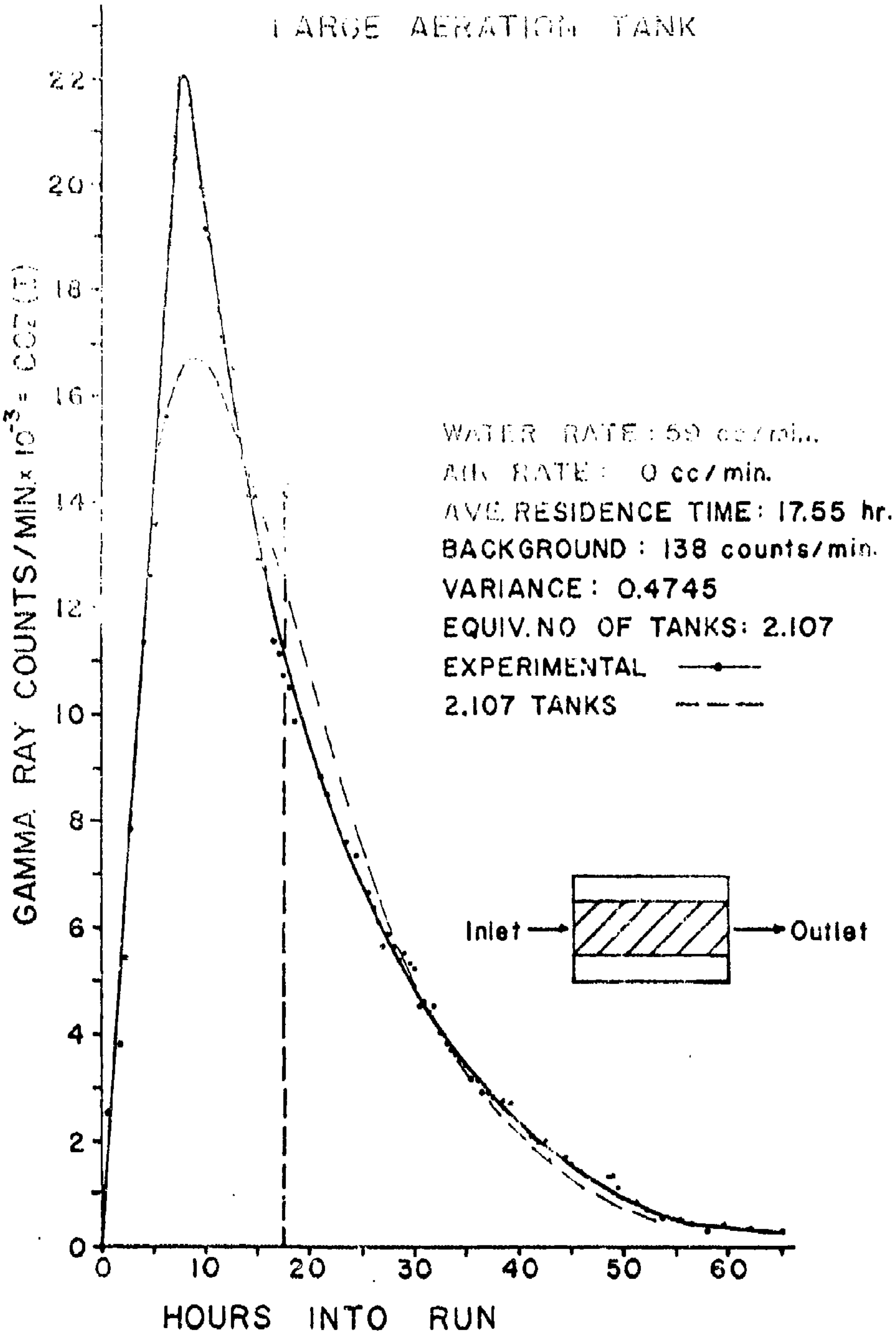


FIGURE
ONE AERATION TANK
RUN 1.
RUN 2.
RUN 3.
RUN 4.
ONE WELL MIXED TANK.
C(θ) = E(θ)
θ
1.0
.8
.6
.4
.2
0
1
2
3
4
5
6
7

FIGURE 7

LARGE AERATION TANK



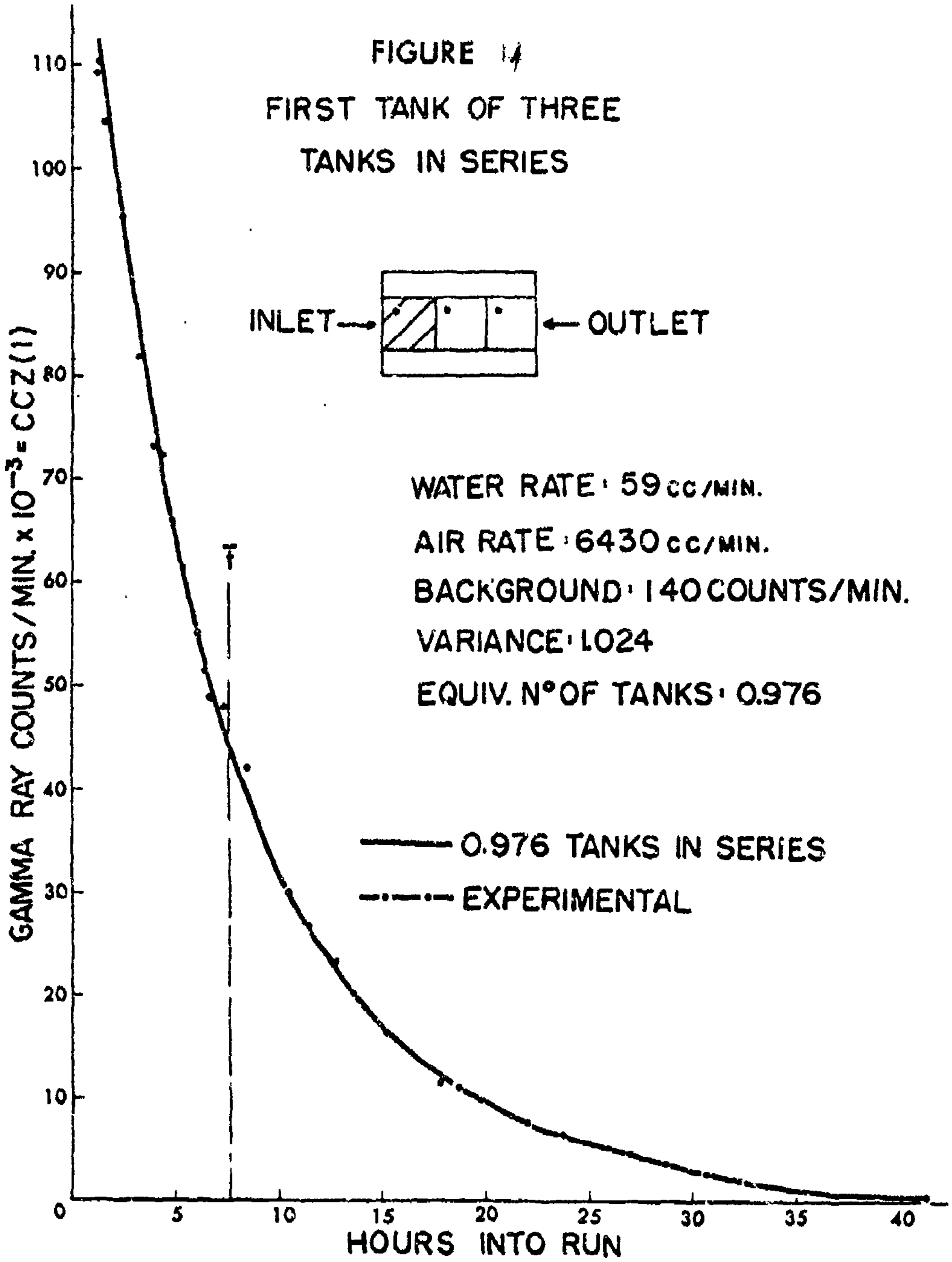


FIGURE 14
FIRST TANK OF THREE
TANKS IN SERIES
INLET
OUTLET
WATER RATE: 59 cc/MIN.
AIR RATE: 6430 cc/MIN.
BACKGROUND: 140 COUNTS/MIN.
VARIANCE: 1.024
EQUIV. N° OF TANKS: 0.976
0.976 TANKS IN SERIES
EXPERIMENTAL
GAMMA RAY COUNTS/MIN. x 10^-3 = CCZ(1)
HOURS INTO RUN
0
5
10
15
20
25
30
35
40
50
60
70
80
90
100
110

FIGURE 5

LAST TWO TANKS OF THREE TANKS IN SERIES

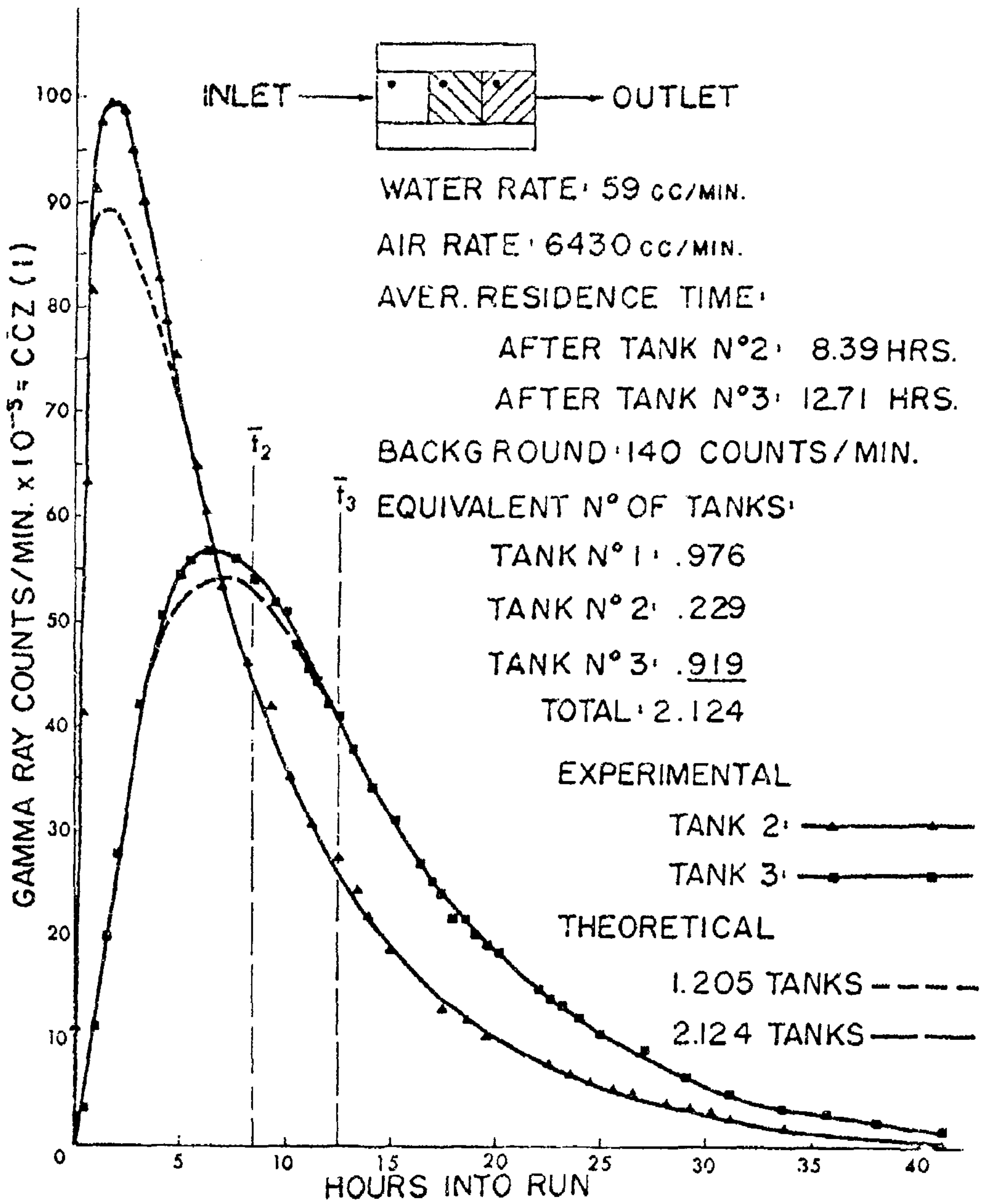
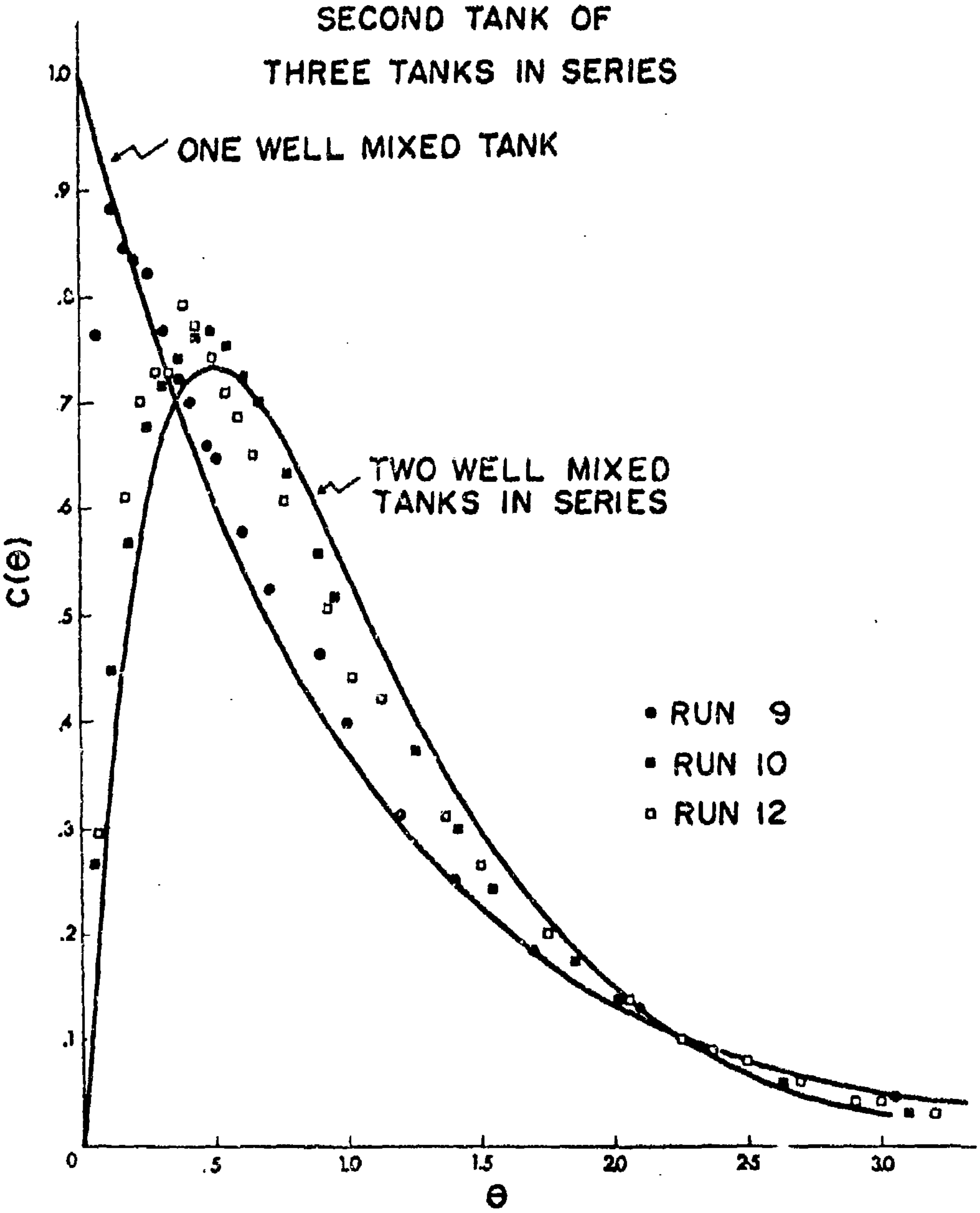


FIGURE 6

SECOND TANK OF
THREE TANKS IN SERIES



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13. ABSTRACT

Th ~~This~~ report describes the work undertaken to represent and identify mathematical models of biological waste treatment as applied to laboratory sized aeration basins. Pulse inputs of radioactive sodium-24 have been used to obtain residence time distribution curves (impulse response curves) for the basins. Reproducible experimental data are easy to obtain, and the basin parameters computed from the data agree well with the known parameters if care is taken to use experimental data for periods longer than 8-10 residence times. Otherwise, the data can be misleading. ~~(U)~~

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14. KEY WORDS	LINK A		LINK B		LINK C	
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